THE PEDAGOGICAL POTENTIAL OF USING DIGITAL GRAPHIC TOOLS IN DEVELOPING STUDENTS' SPATIAL THINKING IN ENGINEERING GRAPHICS EDUCATION

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Abstract. This article theoretically and methodologically examines the pedagogical potential of digital graphic tools for developing students' spatial thinking in engineering graphics education. Spatial thinking is interpreted as a complex cognitive process associated with reading engineering drawings, understanding projections, sections and cuts, mentally representing three-dimensional forms, and transforming graphic information between different representations. The paper discusses the integration of 2D drawings, 3D models, interactive visualization and CAD environments into a coherent didactic sequence. The reviewed literature indicates that CAD-based instruction and intentionally designed spatial visualization activities can contribute to the development of students' spatial skills. A staged model for developing spatial thinking, pedagogical conditions, task system, assessment criteria and methodological directions for teachers are proposed. The approach treats digital tools not merely as technologies for producing drawings, but as a pedagogical environment for developing spatial thinking.

Keywords: engineering graphics, spatial thinking, spatial representation, spatial visualization, digital graphic tools, CAD, 3D modeling, graphic competence, pedagogical technology.

ПЕДАГОГИЧЕСКИЙ ПОТЕНЦИАЛ ИСПОЛЬЗОВАНИЯ ЦИФРОВЫХ ГРАФИЧЕСКИХ ИНСТРУМЕНТОВ ДЛЯ РАЗВИТИЯ ПРОСТРАНСТВЕННОГО МЫШЛЕНИЯ У СТУДЕНТОВ В РАМКАХ ОБУЧЕНИЯ ИНЖЕНЕРНОЙ ГРАФИКЕ.

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Аннотация. В статье теоретически и методически рассматриваются педагогические возможности использования цифровых графических средств

для развития пространственного мышления студентов в процессе обучения инженерной графике. Пространственное мышление рассматривается как сложный когнитивный процесс, связанный с чтением инженерных чертежей, пониманием проекций, сечений и разрезов, мысленным представлением трехмерной формы и преобразованием графической информации из одного вида в другой. Анализируются возможности объединения 2D-чертежа, 3D-модели, интерактивной визуализации и CAD-среды в единую дидактическую последовательность. Анализ научных источников показывает, что CAD-ориентированное обучение и специально организованные задания по пространственной визуализации могут способствовать развитию пространственных навыков студентов. Предлагаются поэтапная модель развития пространственного мышления, педагогические условия, система заданий, критерии оценки и методические направления деятельности преподавателя. Подход ориентирован на использование цифровых средств не только как инструмента выполнения чертежей, но и как педагогической среды развития пространственного мышления.

Ключевые слова: инженерная графика, пространственное мышление, пространственное представление, пространственная визуализация, цифровые графические средства, CAD, 3D-моделирование, графическая компетентность, педагогическая технология.

Introduction

Engineering graphics is one of the fundamental disciplines in higher education that a student needs in order to express a technical object through graphic language, read drawings, understand geometric relationships and visualize design solutions. Within this discipline, knowledge is not limited to memorizing the rules for producing drawings. The student must be able to comprehend a three-dimensional object from a two-dimensional graphic image, view the object from different viewpoints, determine the spatial relationships between its elements and, conversely, represent an imagined spatial object by means of standard graphic tools. Therefore, the outcome of engineering graphics education depends not only on the technical accuracy of graphic activity, but also on the level of development of spatial thinking.

In the scientific literature, spatial ability is considered one of the important factors associated with success in engineering graphics and engineering education. Marunić and Glažar emphasize the need for a balanced organization of course

content and training, based on research findings, in order to develop spatial ability in engineering graphics education [1]. Their subsequent review study shows that the development of 3D CAD technologies has further increased interest in the issue of developing and assessing spatial ability [2].

The introduction of digital technologies into education is also changing the methodology of engineering graphics. With CAD (Computer-Aided Design) systems, the student can perceive a drawing not as a static image, but as a dynamic object that can be rotated, zoomed, sectioned, whose elements can be hidden or restored, whose dimensions can be changed, and whose 3D model can be observed in various projections. Such capabilities require the digital tool to be considered not as a mere technical aid, but as a didactic tool that organizes cognitive activity.

Within UNESCO's ICT Competency Framework for Teachers, it is also noted that the purposeful integration of digital technologies into the educational process has the potential to transform the pedagogical process and to engage learners more actively [9]. In the context of engineering graphics, this principle is particularly important: a digital graphic tool should not merely allow the student to view a ready-made image, but should create conditions for the student to create, modify, check and explain the image.

Relevance of the topic. In today's engineering practice, a large part of graphic information is created and processed in a digital environment. Consequently, the content of graphic training in higher education is becoming closely linked with digital modeling, visualization and interactive graphic environments. However, the mere use of a digital tool does not mean that spatial thinking develops automatically. If a student merely mechanically repeats a sequence of commands in a CAD program, he or she may master the software operations, yet the skill of independently visualizing an object from a drawing or analyzing a model may not be sufficiently developed.

In a study by Kösa and Karakuş devoted to engineering students, the relationship between a CAD-based engineering drawing course and spatial visualization skills was examined using an experimental design. The study involved 116 first-year engineering students, and it was reported that CAD-based activities had a positive effect on the development of spatial visualization skills [3]. This result demonstrates the importance of combining digital graphic tools with a methodology aimed at developing spatial thinking.

González Campos, Sánchez-Navarro and Arnedo-Moreno empirically studied the effect of a computer graphics course on visual-spatial abilities and showed that studying in a computer graphics course may be associated with stronger visual-spatial abilities [4]. Onyancha, Derov and Kinsey, in turn, analyzed earlier studies showing that spatial ability can be developed through targeted exercises and participation in a CAD course [5].

From this point of view, the didactic justification of the sequence "2D drawing — spatial visualization — 3D model — analysis — graphic re-representation" in engineering graphics education is one of the pressing issues. This article focuses not on digital graphic tools themselves, but on how to link them with pedagogical tasks, which tasks to assign at which stages, and by which criteria to assess the outcome.

Purpose of the study. The purpose of the study is to identify the pedagogical potential of using digital graphic tools to develop students' spatial thinking in engineering graphics education, to systematize them didactically and to propose a model for their staged application.

Object and subject of the study. The object of the study is the process of teaching engineering graphics in higher education. The subject of the study is the pedagogical conditions and methodological techniques for developing students' spatial thinking in this process by means of digital graphic tools, 2D/3D modeling, visualization and graphic tasks.

Research methods. The study employed analysis of scientific and pedagogical literature, comparison, systematization, generalization, methodological interpretation of experience in engineering graphics education, and the construction of a pedagogical model. Works in foreign research that examined the relationship between spatial ability, CAD, 3D modeling and graphics education were analyzed in terms of content [1–8]. The pedagogical model presented in the article is the author's methodological proposal; it was developed not as a direct copy of the approaches described in the sources, but on the basis of adapting them to the conditions of engineering graphics education.

The content of spatial thinking in engineering graphics education

Spatial thinking encompasses a person's ability to mentally visualize, retain, rotate and reorganize three-dimensional objects, their parts, their mutual arrangement and their changes in space. Its importance for engineering graphics lies in the fact that a drawing often presents not the real object itself, but its standardized graphic

representation. The student must reconstruct the spatial structure of the object on the basis of lines, dimensions, projections and conventional symbols.

Marunić and Glažar identify spatial ability as an important component associated with success in engineering graphics education and note that it can be developed through education and training [1]. In this regard, it is methodologically appropriate to view spatial thinking not as a single general ability, but as a set of interrelated activities such as positioning an object in space, mental rotation, understanding the relationship between projections, and relating parts to the whole.

In an engineering graphics class, spatial thinking manifests itself in the following activities: visualizing the overall shape of a part from two or three given projections; determining the missing view of a part; understanding the internal structure of an object from a section or cut; predicting the change in appearance when a part is rotated through a certain angle in space; generating the corresponding 2D projections from a 3D model; analyzing the mutual arrangement of the design features shown in a drawing.

Therefore, the outcome of developing spatial thinking should not be measured solely by the ability to “see the object.” It is also important that the student can link spatial visualization with graphic activity, express his or her ideas through a drawing or a model, find an error in a model and explain his or her own solution.

The pedagogical potential of digital graphic tools

In this article, digital graphic tools are understood as CAD systems serving 2D drafting and 3D modeling, interactive visualization tools and digital graphic environments. Their pedagogical value is determined not by the number of commands in the software or the abundance of its technical capabilities, but by the degree to which they support cognitive activity in line with the learning objective.

The first opportunity is visual feedback. With a traditional paper drawing, the student often notices an error only after the result is complete. In a CAD environment, however, an error can be detected during the process by rotating or zooming the object, checking coordinates or obtaining another view of the model. This also creates favorable conditions for the teacher to discuss the student’s thinking process.

The second opportunity is the rapid switching between different representations of a single object. For example, by moving between the 3D model of a part, the front view, the top view and the side view, the student directly observes

the connection between the projections and the spatial object. This strengthens the semantic link between 2D and 3D images.

The third opportunity is dynamic experimentation. The student can change one parameter of a part and observe how its relationship with other elements changes. Such activity develops parametric thinking and at the same time helps in understanding cause-and-effect relationships.

The fourth opportunity is individualization. A student with strong spatial visualization can be given a more complex part or a multi-stage project, while a struggling student can be offered simplified tasks that start from geometric primitives. In this case, differentiating task complexity within the same topic becomes a means of pedagogical management.

The fifth opportunity is repeated visualization. In the multimodal approach studied by Bairaktarova, Williams and Katsioloudis, classroom sessions were combined with activities such as video materials, hand sketching, and working with CAD and 3D objects; the study reported statistically significant improvements in certain spatial measures and in the results of a drawing task [6]. This shows that a digital tool should not replace other graphic activities, but should be integrated with them.

The didactic connection between 2D and 3D images

In engineering graphics education, it is methodologically incorrect to set 2D and 3D environments against each other. The 2D drawing remains the standard means of engineering communication, while the 3D model serves as an additional representation that makes it possible to explain and verify the spatial structure of the object. Therefore, the student must learn to move from one representation to the other.

From a pedagogical point of view, the following cycle may be effective: first, the drawing is analyzed; then the geometric elements of the object are identified; next, the student describes the spatial shape verbally or through a sketch; at the following stage, a 3D model is built; the model is checked by rotating it; then 2D projections are generated from it and compared with the original drawing. An important feature of this cycle is that the student does not copy a ready-made model, but reinterprets the graphic information.

The study by Kösa and Karakuş shows that CAD-based engineering drawing activities can be linked to spatial visualization [3]. At the same time, a systematic review on engineering design and spatial skills published in 2026 emphasizes that

the evidence on the relationship between spatial skills and design outcomes is not uniform, and that spatial skills need to be considered together with applied engineering graphics — sketching and CAD [10]. Hence, the model proposed in this article views spatial thinking not as a separate "test ability," but as a competence that develops together with graphic activity.

Pedagogical conditions for developing spatial thinking

The availability of digital tools does not in itself guarantee learning outcomes. To turn them into a means of developing spatial thinking, a number of pedagogical conditions are necessary.

• clear setting of the learning objective: each CAD task should be linked to a specific spatial operation — rotation, decomposition, projection, comparison or analysis;

• the principle of moving from simple to complex: a gradual transition from geometric primitives toward design features and complex parts;

• 2D–3D integration: the drawing, the sketch and the solid model should be used as mutually complementary learning tools;

• active learning: the student should not be an observer of a ready-made model, but an active participant in the process of creating, modifying and checking the model;

• problem-based tasks: graphic problems should be assigned that require searching for a solution rather than repeating a single command;

• reflection: the student should explain the error in his or her drawing or model, determine at which stage the problem arose and indicate how to correct it;

• differentiated approach: adapting task complexity for students with different levels of spatial preparedness.

A staged model for developing spatial thinking

On the basis of generalizing the research findings, the author proposes a six-stage model for developing spatial thinking. The main idea of the model is the consistent development of the student's graphic activity from recognizing a geometric shape to independent spatial-constructive activity. This model is regarded not as the result of practical experimentation, but as a methodological proposal developed on the basis of the analyzed scientific and methodological sources and the didactic logic of engineering graphics education.

Stage	Learning content	Main spatial operation	Digital activity	Expected outcome

I	Geometric primitives	Recognizing a shape and positioning it in space	Working with 2D/3D primitives	Basic spatial visualization
II	Geometric constraints	Understanding the relationships between elements	Parallel, perpendicular, concentric and symmetric constraints	Accuracy and logical thinking
III	2D projections	Reconstructing the 2D–3D connection	Comparing views and moving to a 3D model	Projective thinking
IV	Simple 3D parts	Mental rotation and analysis	Rotating the model, checking sections and views	Spatial visualization
V	Complex design models	Relating parts to the whole	Modeling with features and parameters	Spatial-constructive analysis
VI	Graphic project	Independent spatial solution	Model–drawing–analysis–presentation cycle	Comprehensive graphic competence

Table 1. A staged model for developing spatial thinking. Source: developed by the author on the basis of an analysis of scientific and methodological sources.

System of graphic tasks

In developing spatial thinking, the content of the task is of decisive importance. A simple task such as “draw the part in a CAD program” does not fully reveal the student’s spatial thinking. A task should require the student to perform several thinking operations in sequence.

Tasks of the first type focus on geometric identification. The student is given a cube, prism, cylinder, cone or a combination of them and is asked to identify their main geometric elements. At the next stage, the student is required to determine the mutual arrangement, symmetry, axes and dimensions of these elements. This stage prioritizes geometric thinking over software commands.

Tasks of the second type are aimed at reconstructing a 3D shape from a 2D image. For example, the front, top and side views of a part are given; the student first expresses the spatial structure of the object verbally or through a freehand sketch, and then creates a model in the CAD environment. Here the software is used not as

something that “shows the answer,” but as a tool for checking the student’s own hypothesis.

Tasks of the third type focus on generating 2D projections from a 3D model. After building the model, the student generates its front, top and side views, and then justifies which view represents which design feature of the part more clearly. In this way, the choice of graphic representation also becomes part of the process of spatial analysis.

Tasks of the fourth type are based on error detection. The student is given a deliberately incorrectly built model or an incorrectly projected part. He or she must identify the error, explain its cause and correct the model. Such tasks strengthen analytical and reflective activity.

Tasks of the fifth type require mental rotation. Looking at the initial position of a part, the student predicts which faces will become visible or how a given projection will change when the part is rotated in a certain direction. The model is then rotated in the CAD environment and the prediction is checked. Here the digital tool does not replace the student’s answer, but becomes a means of checking the result of his or her thinking.

Tasks of the sixth type are organized as an independent graphic project. The student selects a real or hypothetical part, analyzes its geometric structure, creates a 3D model, generates the main 2D views, explains the design features and defends the final result. At this stage, spatial thinking becomes integrated with the other components of graphic competence

Methodological directions of the teacher’s activity in a digital environment

In a digital graphic environment, the teacher’s role should not be limited to demonstrating software commands. First of all, the teacher develops questions that activate spatial thinking. For example, questions such as “How is the interior of this part arranged?”, “If the object is rotated by 90 degrees, which faces will be visible?”, “Which projection shows this element more clearly?”, “Which other elements will this change in the model affect?” link the student’s graphic actions with cognitive activity.

During a demonstration, it is advisable for the teacher to show the process of solving the problem rather than spending a long time displaying the finished result. In doing so, the thinking algorithm is revealed through questions such as “what needs to be determined first?”, “which geometric primitive can we start from?”, “which constraint is the main one?”, “which method of checking the model shall we use?”.

The teacher should also not confuse technical difficulties in using a digital tool with spatial thinking. A student's lack of knowledge of CAD commands and a low level of spatial visualization are not the same phenomenon. Therefore, in assessment it is advisable, as far as possible, to track software proficiency and spatial-cognitive outcomes through separate indicators.

In assessing spatial thinking, relying on quality alone is not sufficient. The student's ability to visualize the object, link projections, analyze the model and justify his or her own solution should also be taken into account.

Criterion	High level	Intermediate level	Basic level
Spatial visualization	Visualizes the shape of the object independently and accurately	Understands the basic shape; needs help with some elements	Has considerable difficulty reconstructing the spatial shape
2D–3D connection	Independently establishes the connection between projections and the model	Partially establishes the connection	Has difficulty understanding the connection between views
Mental rotation	Can accurately predict changes in space	Can perform simple rotations	Has difficulty visualizing the result of a rotation
Graphic analysis	Finds the error, explains its cause and corrects it	Finds the error but needs help explaining it	Has difficulty identifying the error
Use of CAD	Uses the digital tool purposefully and independently	Uses the basic tools	Performs operations mainly by following instructions
Reflection	Justifies the solution and indicates ways to improve it	Evaluates his or her work in general terms	Has difficulty explaining the result

Table 2. Criteria for assessing spatial thinking. Source: system of criteria proposed by the author.

Discussion

The analyzed studies shed light on the relationship between digital graphic tools and spatial skills using various methods. Marunić and Glažar provided a theoretical justification for the role of spatial ability in engineering graphics education [1; 2]. Kösa and Karakuş, through a quasi-experimental study comparing CAD-based instruction with a control group, concluded that it had a positive effect on the development of spatial visualization [3]. González Campos and co-authors

demonstrated the link between a computer graphics course and visual-spatial ability on the basis of empirical data [4]. Onyancha and co-authors, in turn, analyzed the effect of targeted training and CAD-related learning on spatial ability [5].

However, it would be wrong to reduce these results to the simplistic conclusion that “the use of CAD software alone is sufficient.” The 2026 systematic review notes that studies on the relationship between spatial skills and engineering design do not reach uniform conclusions, and that although some works show a correlation, the experimental designs have not always been sufficient to prove a causal relationship [10]. Therefore, the methodology for using digital tools should be considered together with the learning objective, task content and assessment criteria.

On the other hand, the visual capabilities of the 3D environment may also create the risk of making the student excessively dependent on a ready-made model. If the teacher immediately demonstrates every problem in 3D, the student may engage less in the activity of independently reconstructing a spatial object from a 2D drawing. For this reason, the principle of “first a hypothesis — then digital verification” occupies an important place in the methodological sequence.

The main distinction of the approach proposed in this article is that the digital graphic tool is regarded not as an end in itself, but as a means of activating spatial thinking operations. In this approach, the process of building a 3D model is combined with drawing reading, geometric analysis, mental rotation, projection, error detection and reflection.

Scientific novelty

The scientific and methodological novelty of the article lies in the proposal to organize digital graphic activity aimed at developing spatial thinking in engineering graphics education on the basis of a unified staged didactic model. The model defines a consistent developmental path from understanding geometric primitives through the 2D–3D connection, spatial visualization and design analysis to an independent graphic project.

In addition, the article systematizes the pedagogical potential of digital graphic tools in five directions: visual feedback, switching between representations, dynamic experimentation, individualization and repeated visualization. These opportunities were linked to the corresponding operations of spatial thinking. The proposed assessment criteria make it possible to track spatial visualization, the 2D–3D connection, mental rotation, graphic analysis, use of CAD and reflection separately.

Practical significance

The proposed methodological approach can be applied in designing practical classes in engineering graphics, engineering computer graphics, descriptive geometry and CAD-based disciplines. On the basis of the stages in the table, the teacher can construct tasks sequentially, integrate 2D and 3D activities for each stage and assess students' results according to the criteria.

The approach can also be used in developing individual learning pathways. For example, students with weak spatial visualization can be given tasks that start with geometric primitives and simple combinations, after which the 2D–3D transition is made more complex. Students with a higher level of preparedness, in turn, are directed toward parametric changes, complex design features and independent graphic projects.

In the future, it would be advisable to test this methodological model through experimental work, to measure the results of control and experimental groups using spatial visualization tests and practical graphic tasks, and to determine the transferability of the methodology across different CAD platforms. In doing so, the results could be assessed comprehensively not only by test scores, but also by drawing accuracy, task completion time, number of errors, independence and reflective comments.

Conclusion

Developing students' spatial thinking in engineering graphics education is an important component of graphic training. Spatial thinking encompasses interrelated activities such as reading drawings, understanding projections, visualizing a three-dimensional object, mental rotation, analyzing a model and re-expressing it in graphic form.

The analysis of scientific sources shows that CAD-based classes, computer graphics courses and targeted spatial training may be associated with the development of students' spatial skills [3–6]. At the same time, recent systematic reviews indicate the need not to interpret this relationship in an oversimplified way and to develop spatial skills together with applied graphic activity [10].

According to the methodological approach proposed in the article, the use of digital graphic tools should not be confined to "teaching software commands," but should combine the 2D drawing, spatial visualization, 3D modeling, analysis, projection and reflection into a single pedagogical cycle. In this way, the student develops not as a spectator of a ready-made 3D model, but as an active subject who independently interprets and verifies graphic information.

Thus, the pedagogical effectiveness of digital graphic tools in engineering graphics education is determined not only by their technical capabilities, but also by the cognitive structure of the learning task, its gradual increase in complexity, the didactic integration of 2D and 3D images, an individual approach and reflective assessment. Testing the proposed model experimentally at the next stage will help to further strengthen the scientific foundations of the methodology for developing spatial thinking in engineering graphics education.

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